Back

Yankee Rowe

Yankee Rowe is a 167-MWe PWR with a startup date of August 19, 1960. It started commercial operation in July, 1961 and was shutdown in October, 1991 following 21 fuel cycles and 8,052 EFPD. In the 1993 decommissioning plan submitted to the NRC, systems with significant internal surface contamination were identified, as shown in Table A-10 (Yankee Atomic 1995).

Table A-10. Average Internal Contamination Levels of Reactor Systems at Yankee Rowe

System	Surface Contamination Level (dpm/100 cm^2)
Main Coolant	7.1e+09
Spent Fuel Cooling	3.3e+08
Waste Disposal	1.2e+07
Primary Plant Vent & Drain	1.2e+07
Charging & Volume Control	1.2e+07
Shutdown Cooling	1.2e+07
Fuel Handling	1.7e+06
Letdown/Purification	1.4e+06
Primary Plant Sampling	1.4e+06
Safety Injection	1.4e+05
Safe Shutdown	1.4e+05
Vol. Control Heating & Cooling	1.2e+04
Vol. Control Vent. & Purge	1.2e+04
Post Accident H_2 Control	1.2e+04
Chemical Shutdown	1.1e+04

The data on facilities that have submitted decommissioning plans have limited applicability to a generic analysis because of: (1) their limited years of operation, (2) abnormal events and operating conditions that prompted premature shutdown and/or, (3) size and design of the facilities.

A.3.2.3 Levels of Internal Surface Contamination Derived for Reference BWR

Internal surface contamination levels in BWR systems and piping reflect the radionuclide concentrations in the reactor coolant, steam and condensate. Summary estimates of activities in corrosion films deposited on internal surfaces of equipment and piping are cited by Oak et al. (1980) for a Reference BWR.

The radionuclide composition of corrosion films is shown in Table A-11. About 86% of the estimated inventory at shutdown was due to two nuclides, Co-60 and Mn-54 (Co-60 constituted nearly half of the total inventory). It should be noted that internal surface deposited nuclides generally do not include large amounts of fission products. Although fission products do exist in the reactor coolant, they are generally soluble and remain in solution rather than plate out along with neutron-activated corrosion products. The buildup of coolant contaminants is controlled by the CVCS system, which continuously removes both insoluble (particulate) and soluble contaminants.

Table A-11. Activated Corrosion Products in the Reference BWR

Nuclide	Half-Life	Relative Activity at Various Times After Shutdown*			
		0	10 y	30 y	50 y
Cr-51	27.7 d	2.1e-02	—	—	—
Mn-54	312.1 d	3.9e-01	1.2e-04	—	—
Fe-59	44.5 d	2.5e-02	—	—	—
Co-58	70.88 d	9.3e-03	—	—	—
Co-60	5.271 y	4.7e-01	1.3e-01	9.1e-03	6.6e-04
Zn-65	244.26 d	6.1e-03	1.9e-07	—	—
Zr-95	64.02 d	4.0e-03	—	—	—
Nb-95	34.97 d	4.0e-03	—	—	—
Ru-103	39.27 d	2.3e-03	—	—	—
Ru-106	373.6 d	2.8e-03	3.2e-06	—	—
Cs-134	2.065 y	1.9e-02	—	—	—
Cs-137	30.07 y	3.4e-02	2.7e-02	1.7e-02	1.1e-02
Ce-141	32.5 d	3.0e-03	—	—	—
Ce-144	284.9 d	8.1e-03	1.1e-06	—	—
Total		1.0	1.5e-01	2.6e-02	1.1e-02

*Activities of individual nuclides, normalized to the total activity at shutdown

The total radionuclide inventory has been estimated at 8,500 curies, with 6,300 curies associated with internal equipment surfaces and the remaining 2,200 curies associated with internal piping surfaces (see Table A-12).

Table A-12.
Distribution of Activated Corrosion Products on Internal Surfaces of Reference BWR

Location	Surface Area (m^2)	Areal Activity Concentration (Ci/m^2)	Total Surface Activity (Ci)
Piping	3.4e+04	6.5e-02	2.2e+03
Equipment:			
Reactor Building	8.6e+03	2.2e-01	1.9e+03
Turbine Building	2.0e+05	6.0e-03	1.2e+03
Radwaste & Control	1.4e+03	2.3e+00	3.2e+03
Total	2.4e+05	2.6e+00	8.5e+03

Source: Oak et al. 1980, vol. 1, Table 7.4-10

For the residual inventory of 6,300 curies on equipment, an estimated 30% was associated with equipment in the reactor building, about 19% was associated with the condenser and feed-water heaters located in the turbine building, and about 51% involved internal deposition on equipment in the radwaste and control building.

Of the 2,200 curies present in piping, approximately 56% were estimated to be associated with the reactor coolant piping and 44% with condensate piping. Presented below is a more thorough analysis of piping data.

Contaminated Piping

Internal surface contamination levels of BWR piping can be most useful when grouped according to direct or indirect contact with reactor coolant, steam/air and condensate. Deposition levels for reactor coolant and condensate were based on empirical dose rate measurements that were correlated to contamination levels for a specific pipe size and schedule. A summary of measured dose rate data and derived deposition levels is shown in Table A-13.

Table A-14 provides a detailed accounting of radionuclide inventories derived for various size piping made of aluminum, carbon steel, and stainless steel in contact with reactor coolant, steam/air, or condensate.

Table A-13. Contact Dose Rate and Internal Surface Activity of BWR Piping

Medium in Pipes	Nominal O.D. (mm)	Wall Thickness (mm)	Contact Dose Rate (mR/hr)	Areal Activity Concentration (Ci/m^2)
Reactor Coolant	610	59.5	700	1.1
Steam/Air	914	20.4	70	0.005
Condensate	610	26.0	50	0.05

Contaminated Equipment

Contamination on internal surfaces of BWR equipment in contact with reactor coolant was estimated from measurements taken on the heat exchanger in the reactor coolant cleanup system. In general, equipment in contact with steam or condensate was assumed to reach the same levels as previously cited for BWR piping. Exceptions were the lower values assigned to steam surfaces for the turbine and feedwater heaters. Table A-15 provides estimates of contamination levels assigned to BWR equipment.

Table A-16 identifies the major system components and radionuclides inventories based on location and contact with reactor coolant, steam, condensate and radwaste.

A.3.2.4 Levels of Internal Surface Contamination for Reference PWR

Radioactive contamination levels associated with internal surfaces of piping and equipment for a Reference PWR have been estimated by Smith et al. (1978). At time of shutdown, the fractional contributions of various radionuclides deposited on internal surfaces of the primary loop of a PWR are shown in Table A-17.

Estimates of internal surface activity concentrations for major systems and components were based on models which correlated external dose rate measurements with internal contamination analyses, taking into account source geometry and shielding factors (see Table A-18). Empirical dose rate measurements showed that reactor vessel and steam generator internal surfaces in contact with primary coolant, on average, would yield contamination levels of about 0.23 Ci/m^2 at time of shutdown.

Table A-14. Estimates of Internal Contamination for Reference BWR Piping

Pipe Material/ Contact Medium	Outer Diameter (mm)																		Total		
	60			152			356			533			660			914					
	L (m)	A (m^2)	Act. (Ci)	L (m)	A (m^2)	Act. (Ci)	L (m)	A (m^2)	Act. (Ci)	L (m)	A (m^2)	Act. (Ci)	L (m)	A (m^2)	Act. (Ci)	L (m)	A (m^2)	Act. (Ci)	L (m)	A (m^2)	Act. (Ci)
Aluminum																					
Steam/Air	4,300	81	0.4	1,400	640	3.2	130	140	0.7	—	—	—	—	—	—	—	—	—	5,830	861	4
Condensate	—	—	—	14	6.7	0.3	—	—	—	—	—	—	—	—	—	—	—	—	14	7	0.3
Carbon Steel																					
Rx coolant	380	71	78	1,500	700	770	61	68	75	55	92	100	—	—	—	—	—	—	1,996	931	1,023
Steam/Air	1,200	220	1.1	1,800	880	4.4	5,600	6,300	32	1,200	2,000	10	950	200	9.8	440	1,300	6.3	11,190	10,900	64
Condensate	7,400	1,400	7.0	8,300	3,900	200	5,100	5,700	280	2,800	4,600	230	370	770	38	210	610	31	24,180	16,980	786
Stainless Steel																					
Rx coolant	8	1.5	1.6	34	16	18	61	68	75	55	92	100	—	—	—	—	—	—	158	178	195
Steam/Air	280	53	0.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	280	53	0
Condensate	7,000	1,300	66	1,600	780	39	220	240	12	—	—	—	—	—	—	—	--	—	8,820	2,320	117
Total	20,568	3,127	154	14,648	6,923	1,035	11,172	12,516	475	4,110	6,784	440	1,320	970	48	650	1,910	37	52,468	32,229	2,189

Note: Average contamination level = 68 mCi/m^2 (1.5 x 10^9 dpm/100 cm^2)

Table A-15. Summary of Contamination Levels in BWR Equipment

Equipment Category	Areal Activity Concentration (Ci/m^2)
Reactor Coolant Equipment	3.6e-01
Steam Equipment	5.0e-03
Turbine	5.0e-04
Condensate Equipment	5.0e-02
Main Condenser	5.0e-03
Feedwater Heaters	5.0e-03
Concentrated Waste Tanks/Equipment	5.0e+00

The total surface activity on the reactor vessel and its internal components, which have a total surface area of 570 m^2, was estimated to be about 130 Ci. The surface activity on the four steam generators, which have a total mass of 1,251 t and a combined surface area of about 19,000 m^2, was estimated to be approximately 4,400 Ci, which represents 90% of the total deposited activity. The areal concentration of activated corrosion products in the 89-metric ton pressurizer was assumed to be about 0.04 Ci/m^2. Since the internal surface area is about 87 m^2, the total deposited activity was estimated to be about 4 Ci.

Table A-16. Estimated Internal Surface Activities in BWR Systems

Building/System	Total Internal Area (m^2)	Areal Activity Concentration (Ci/m^2)	Total Activity (Ci)
Reactor Building			
Fuel Pool Heat Exchangers	8.0e+02	5.0e-02	4.0e+01
Skimmer Surge Tanks	1.0e+02	5.0e-02	5.0e+01
Fuel Pool, Rx Wall, Dryer & Sep. Pool	1.4e+03	5.0e-02	7.0e+01
RBCC Water Heat Exchangers	1.8e+03	5.0e-02	9.0e+01
RMCU Regenerative Heat Exchangers	2.5e+02	3.6e-01	9.0e+01
RWCU Nonregenerative Heat Exchangers	1.7e+02	3.6e-01	6.0e+01
RHR Heat Exchangers	1.5e+03	3.6e-01	5.4e+02
Reactor Vessel	2.6e+03	3.6e-01	9.4e+02
Total	8.6e+03		1.9e+03

Table A-16 (continued)

Building/System	Total Internal Area (m^2)	Areal Activity Concentration (Ci/m^2)	Total Activity (Ci)
Turbine Generator Building			
Main Condenser	7.9e+04	5.0e-03	3.9e+02
Steam Jet Air Ejector Condenser	1.6e+03	5.0e-02	8.0e+01
Gland Seal Steam Condenser	3.5e+02	5.0e-02	1.7e+01
Condensate Storage Tanks	1.6e+03	5.0e-02	8.0e+01
Low-Pressure Feedwater Heaters	7.5e+04	5.0e-03	3.7e+02
Evaporator Drain Tanks	1.0e+01	5.0e-02	5.0e-01
Reheater Drain Tanks	8.4e+02	5.0e-02	4.2e+01
Moisture Separator Drain Tank	3.0e+01	5.0e-03	1.5e-01
Main Turbine	2.6e+03	5.0e-04	1.3e+00
Steam Evaporator	2.0e+03	5.0e-03	1.0e+01
Turbine Bypass Valve Assembly	1.5e+01	5.0e-03	7.5e-01
Moisture Separator Reheaters	1.8e+04	5.0e-03	9.0e+01
Seal Water Liquid Tank	1.2e+01	5.0e-02	6.0e-01
Pumped Drain Tank	2.7e+01	5.0e-02	1.4e+00
High-Pressure Feedwater Heaters	1.7e+04	5.0e-03	8.5e+01
Total	2.0e+05		1.2e+03
Radwaste and Control Building			
Condensate Phase Separator Tanks	1.8e+02	5.0e+00	9.0e+02
Condensate Backwash Receiver Tank	8.5e+01	5.0e+00	4.2e+02
Waste Collector Tank	1.0e+02	5.0e-02	5.0e+00
Waste Surge Tank	1.9e+02	5.0e+00	9.5e+02
Waste Sample Tanks	1.6e+02	5.0e-02	8.0e+00
Floor Drain Collector Tank	1.1e+02	5.0e-02	5.5e+00
Waste Sludge Phase Separator Tank	6.1e+01	5.0e+00	3.0e+02
Floor Drain Sample Tank	7.8e+01	5.0e-02	3.9e+00
Chemical Waste Tanks	1.5e+02	5.0e-02	7.5e+00
Distillate Tanks	1.5e+02	5.0e-02	7.5e+00
Detergent Drain Tank	3.2e+01	5.0e-02	1.6e+01
Decontamination Solution Conc. Waste Tk.	2.3e+01	5.0e+00	1.2e+02
Spent Resin Tank	1.3e+01	5.0e+00	6.5e+01
Cleanup Phase Separator Tanks	6.8e+01	5.0e+00	3.4e+02
Decontamination Solution Concentrator	1.9e+01	5.0e+00	9.5e+01
Total	1.4e+03		3.2e+03

Source: Oak et al. 1980, vol. 2, Table E.2-7

RCS piping includes those sections of piping interconnecting the reactor vessel, steam generators, reactor coolant pumps and various other components, as shown in Figure A-3. RCS

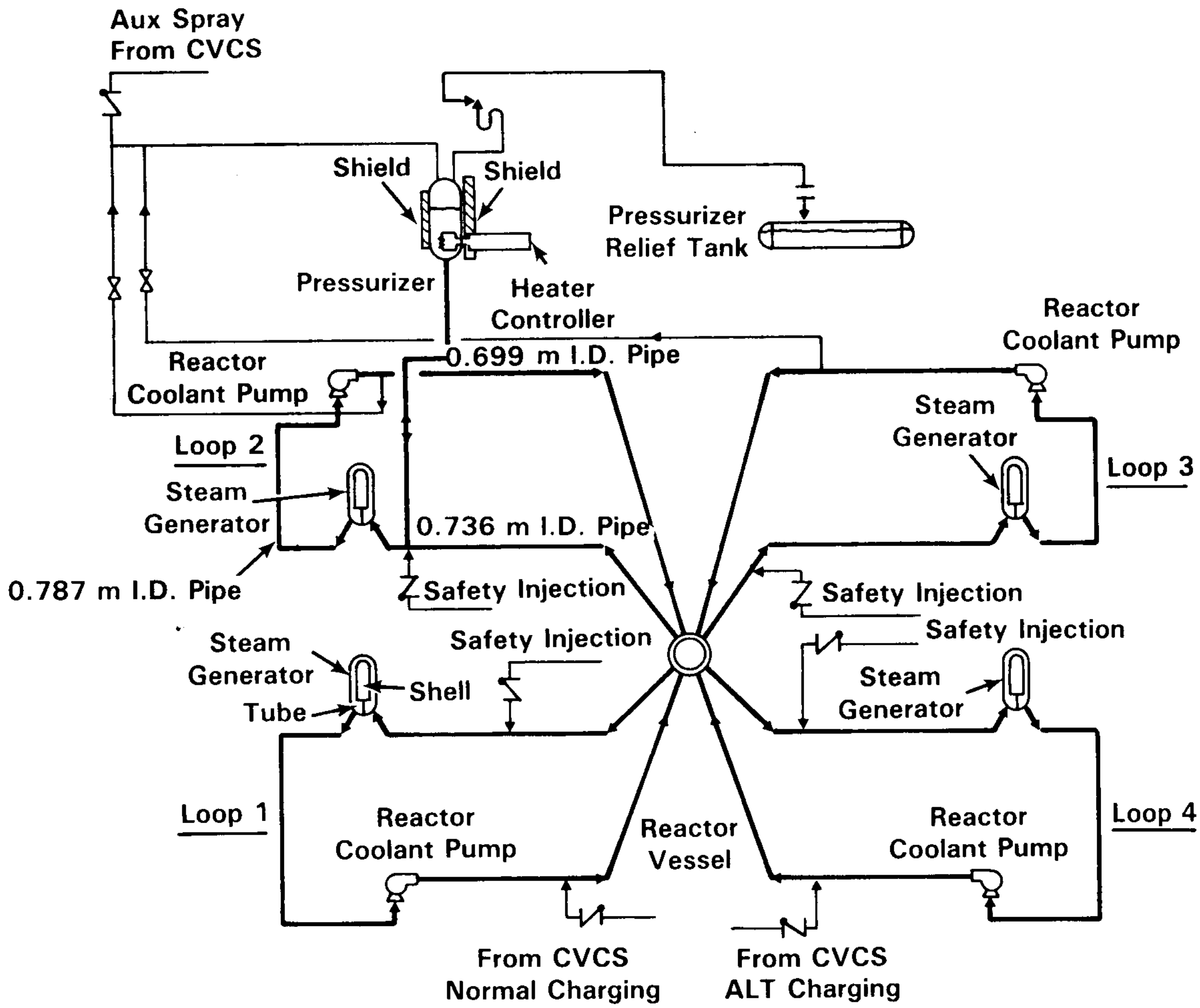

Figure A-3. Reactor Coolant System in a Four-Loop PWR (Abel et al. 1996)

piping primarily involves large diameter, thick-walled pipes. The inside diameter typically ranges from 699 mm to 787 mm, with a corresponding wall thickness of between 59 and 66 mm. From dose rate measurements—about 600 mR/hr—the internal surface activity concentration on RCS piping was estimated at 0.86 Ci/m^2. The total activity on the RCS piping, which has an internal surface area of about 190 m^2 and a mass of 100 t, is estimated to be 160 Ci.

The average activity concentration on the inner surfaces of non-RCS or auxiliary system piping is estimated to be about 0.06 Ci/m^2, based on external dose rate measurements. This value, together with the pipe specifications listed in Table A-19, yields a total surface activity of about 71 Ci on the inner surfaces of all non-RCS PWR piping.

Table A-17. Internal Surface Contamination in the Reference PWR Primary System

Radionuclide	Half-Life	Areal Activity Concentration ($\mu Ci/m^2$)	Relative Activity at Various Times After Shutdown*			
			0	10 y	30 y	50 y
Cr-51	27.7 d	5.30e+03	2.40e-02	—	—	—
Mn-54	312.1 d	8.00e+03	3.60e-02	1.1e-05	—	—
Fe-59	2.73 y	1.80e+03	8.20e-03	—	—	—
Co-58	70.88 d	1.00e+05	4.60e-01	—	—	—
Co-60	5.271 y	7.10e+04	3.20e-01	8.6e-02	6.2e-03	4.5e-04
Zr-95	64.02 d	8.80e+03	5.60e-02	—	—	—
Nb-95	34.97 d	1.20e+04	5.60e-02	—	—	—
Ru-103	39.27 d	5.90e+03	2.60e-02	—	—	—
Cs-137	30.07 y	2.60e+02	1.20e-03	9.5e-04	6.0e-04	3.8e-04
Ce-141	32.5 d	1.50e+04	6.60e-02	—	—	—
Total		2.30e+05	1.0	8.7e-02	6.8e-03	8.3e-04

Source: Smith et al. 1978, vol. 1

*Activities of individual nuclides, normalized to the total activity at shutdown

Table A-18. Activated Corrosion Products on the Interiors of PWR Systems

Systems	Surface Area (m^2)	Areal Activity Concentration (Ci/m^2)	Total Activity (Ci)
Reactor Vessel and Internals	5.7e+02	0.23	130[a]
Steam Generators	1.9e+04	0.23	4,400
Pressurizer	8.7e+01	0.05	4
Piping (Except RCS)	1.1e+03	0.05	60
RCS Piping	1.9e+02	0.84	160
Total	2.1e+04		4,800

Source: Smith et al. 1978, vol. 2, Table C.4-5

[a] Excluding volumetrically distributed activation products

A.3.3 Contamination of External Surfaces of Equipment and Structural Components

External surfaces of system components as well as floors, walls and structural components become contaminated over the operating lifetime of a nuclear power plant from leaks or spills of radioactive materials originating from the reactor coolant. While most liquid contamination remains localized in the vicinity of the leak or spill, some contamination may experience limited transfer through physical contact. More widespread contamination of external surfaces occurs when contaminants become airborne and passively settle out. Airborne contaminants are also the principal source of contamination of ducts, fans, filters and other equipment that are part of the heating and ventilation and air conditioning systems (HVAC).

Table A-19. Non-RCS Contaminated PWR Piping

Nominal Pipe Size (in.)	Schedule	I.D. (in.)	Length (m)	Mass (kg)	Inside Area (m^2)	Total Activity (Ci)
½	80	0.546	120	198	5.2	0.3
	160	0.464	120	238	4.4	0.3
¾	40	0.824	240	205	15.8	0.9
	80	0.742	360	400	21.3	1.3
	160	0.612	570	1,675	27.8	1.7
1	40	1.049	60	152	5.0	0.3
	80	0.957	180	590	13.7	0.8
	160	0.815	420	1,800	27.3	1.6
1½	40	1.610	120	493	15.4	0.9
	80	1.500	330	1,811	39.5	2.4
	160	1.338	540	3,967	57.7	3.5
2	40	2.067	300	1,655	49.5	3.0
	80	1.939	480	3,642	74.3	4.5
	160	1.687	1,050	11,850	141.3	8.5
3	160	2.624	140	2,985	29.3	1.8
4	160	3.438	180	6,128	49.4	3.0
6	160	5.187	300	20,972	124.2	7.5
8	160	6.813	140	15,924	76.1	4.6
10	140	8.500	365	29,750	247.6	14.9
12	140	10.126	90	18,370	72.7	4.4
14	140	11.188	100	25,475	89.3	5.4
Total			6,205	148,280	1186.9	71.2

Radionuclides typically found in the primary coolant and their relative abundance in a PWR and BWR are given in Table A-20 and Table A-21, respectively.

Table A-20. Radionuclides in Primary Coolant in the Reference PWR

Radionuclide	Half-Life	Relative Activity at Various Times After Shutdown*			
		0	10 y	30 y	50 y
Cr-51	27.7 d	6.9e-04	—	—	—
Mn-54	312.1 d	1.4e-03	4.2e-07	—	—
Fe-55	2.73 y	2.2e-02	1.7e-03	1.1e-05	6.7e-08
Fe-59	44.5 d	8.7e-04	—	—	—
Co-58	70.88 d	7.5e-03	—	—	—
Co-60	5.271 y	7.5e-02	2.0e-02	1.5e-03	1.0e-04
Sr-89	50.52 d	1.2e-03	—	—	—
Sr-90+D	28.78 y	6.9e-04	5.4e-04	3.4e-04	2.1e-04
Zr-95	64.02 d	2.5e-04	—	—	—
Nb-95	34.97 d	2.5e-04	—	—	—
Te-129m	33.6 d	3.1e-04	—	—	—
I-131	8.04 d	1.4e-02	—	—	—
Cs-134	2.065 y	1.2e-01	4.2e-03	5.1e-06	6.2e-09
Cs-136	13.16 d	1.1e-03	—	—	—
Cs-137	30.07 y	7.5e-01	6.0e-01	3.8e-01	2.4e-01
Total		1.0	0.62	0.38	0.24

Source: Smith et al. 1978, vol. 1

*Activities of individual nuclides, normalized to the total activity at shutdown

The amount of external surface contamination following 40 years of operation is likely to vary significantly among nuclear power plants and is influenced by fuel integrity, primary coolant chemistry, operational factors and reactor performance. A key operational factor is the effort expended to clean up spills and to decontaminate accessible areas on an ongoing basis.

Although all nuclear utilities conduct routine radiological surveys that assess fixed and removable surface contamination, only limited data have been published in the open literature from which average contamination estimates can be derived. In this section, estimates of external surface contamination are provided that reflect (1) modeled data, (2) data published in the open literature and (3) data from individual utilities that have submitted a decommissioning plan.

Table A-21. Radionuclide Concentrations in Reactor Coolant of Reference BWR

Radionuclide	Half-Life (days)	Specific Activity (μCi/g)	Relative Activity at Various Times After Shutdown*			
			0	10 y	30 y	50 y
P-32	14.28 d	2e-04	1.1e-03	—	—	—
Cr-51	27.7 d	5e-03	5.3e-02	—	—	—
Mn-54	312.1 d	6e-05	7.2e-04	2.2e-07	—	—
Fe-55	2.73 y	1e-03	3.7e-01	2.9e-02	1.8e-04	1.1e-06
Fe-59	44.5 d	3e-05	5.3e-04	—	—	—
Co-58	70.88 d	2e-04	5.6e-03	—	—	—
Co-60	5.271 y	4e-04	2.9e-01	7.8e-02	5.6e-03	4.0e-04
Ni-63	100.1 y	1e-06	3.4e-03	3.2e-03	2.8e-03	2.4e-03
Zn-65	244.26 d	2e-04	1.8e-02	5.7e-07	—	—
Sr-89	50.52 d	1e-04	2.0e-03	—	—	—
Sr-90 +D	28.78 y	6e-06	1.5e-02	1.2e-02	7.3e-03	4.5e-03
Y-91	58.5 d	4e-05	8.1e-04	—	—	—
Zr-95	64.02 d	7e-06	1.6e-04	—	—	—
Ru-103	39.27 d	2e-05	2.9e-04	—	—	—
Ru-106	373.6 d	3e-06	3.9e-04	—	—	—
Ag-110m	249.8 d	1e-06	8.8e-06	3.5e-10	—	—
Te-129m	33.6 d	4e-05	4.9e-04	—	—	—
I-131	8.04 d	5e-03	1.5e-02	—	—	—
Cs-134	2.065 y	3e-05	8.8e-03	3.1e-04	3.7e-07	4.5e-10
Cs-136	13.16 d	2e-05	1.0e-04	—	—	—
Cs-137	30.07 y	7e-05	1.8e-01	1.4e-01	9.0e-02	5.7e-02
Ba-140 +D	12.75 d	4e-04	2.0e-03	—	—	—
Ce-141	32.5 d	3e-05	3.4e-04	—	—	—
Ce-144	284.9 d	3e-06	2.9e-04	4.0e-08	—	—
Pr-143	13.57 d	4e-05	2.0e-04	—	—	—
Nd-147	10.98 d	3e-06	1.2e-05	—	—	—
Total		1.3e-02		2.7e-01	1.1e-01	6.4e-02

* Activities of individual nuclides, normalized to the total activity at shutdown

A.3.3.1 Data for Reference Facilities

Oak et al. (1980) have modeled the surface contamination on structures of the Reference BWR. The model was based on an assumed release rate of one liter of primary coolant per day for 40 years. Levels of deposited contaminants on external surfaces were correlated to ambient dose rates by means of the computer code ISOSHLD and divided into two discrete categories. The first category is low-level contamination, defined by dose rates of 10 mR/hr in air at 1 meter from the surface. The second category was defined as higher contamination with dose rates of 100 mR/hr in air at 1 meter from the surface. Based on the radionuclide composition of Reference BWR coolant, these two contamination levels were estimated to correspond to areal activity concentrations of 2.5×10^{-3} Ci/m^2 and 2.5×10^{-2} Ci/m^2, respectively.

Table A-22 summarizes the distribution of external surface contaminants at shutdown. The total deposited activity on structural surfaces in the Reference BWR was estimated to be 114 curies.

Table A-22. Surface Contamination Levels for Reference BWR at Shutdown

Building	Surface Area (m^2)	Deposited Activity (Ci)	Surface Contamination Level at Shutdown (dpm/100 cm^2)
Reactor Building	**5145**	**74**	**3.19e+08**
Contamination Level 1[a]	2403	5.7	5.27e+07
Contamination Level 2[b]	2742	68.3	5.53e+08
Turbine Generator Bldg.	**1817**	**4.4**	**5.38e+07**
Contamination Level 1[a]	1767	3.2	4.02e+07
Contamination Level 2[b]	50	1.2	5.33e+08
Radwaste & Control Bldg.	**1953**	**35.8**	**4.07e+08**
Contamination Level 1[a]	579	1.4	5.37e+07
Contamination Level 2[b]	1374	34.4	5.56e+08
Total	**8915**	**114.2**	**2.84e+08**

Source: Oak et al. 1980, vol. 2, Table E.2-10

[a] Contamination Level 1 corresponds to 2.5×10^{-3} Ci/m^2.

[b] Contamination Level 2 corresponds to 2.5×10^{-2} Ci/m^2.

Table A-23 provides a more detailed breakdown of contamination levels by identifying major equipment/systems that are located within each of the aforementioned facility buildings.

Table A-23. Estimated External Structural Contamination in the Reference BWR

Building/Associated Equipment/System/Structure	Contaminated Area (m^2)	Contamination Level	Deposited Activity (Ci)
Reactor Building			
Containment Atmosphere Control	1.6e+01	1	4.0e-02
Condensate (Nuclear Steam)	3.3e+01	1	8.2e-02
Control Rod Drive	1.8e+02	1	4.5e-01
Equipment Drain (Radioactive)	1.8e+01	2	4.5e-01
Floor Drain (Radioactive)	7.4e+01	2	1.8e+00
Fuel Pool Cooling & Cleanup	1.2e+03	1	3.0e+00
Fuel Pool Cooling & Cleanup	2.8e+02	2	7.0e+00
High-Pressure Core Spray	1.1e+02	1	2.7e-01
Low-Pressure Core Spray	1.4e+01	1	3.5e-02
Main Steam	3.0e+02	1	7.5e-01
Miscellaneous Wastes (Radioactive)	8.3e+01	1	2.1e-01
Reactor Building Closed Cooling	1.2e+01	1	3.0e-02
Reactor Core Isolation Cooling	1.5e+01	1	3.8e-02
Reactor Water Cleanup	1.5e+02	1	3.8e-01
Reactor Water Cleanup	1.7e+02	2	4.2e+00
Residual Heat Removal	1.7e+02	1	4.2e-01
Standby Gas Treatment	4.0e+01	1	1.0e-01
Traversing Incore Probe	8.0e+01	1	2.0e-01
Primary Containment	2.2e+03	2	5.5e+01
Total			**7.4e+01**
Turbine Generator Building			
Air Removal	3.9e+01	1	9.7e-02
Condensate (Nuclear Steam)	6.6e+02	1	1.6e-01
Condenser Off Gas Treatment	1.8e+02	1	4.5e-01
Equipment Drain (Radioactive)	2.5e+01	2	6.2e-01
Floor Drain (Radioactive)	2.5e+01	2	6.2e-01
Heater Drain	9.1e+01	1	2.3e-01
Main Steam	1.7e+02	1	4.2e-01
Miscellaneous Drain & Vent	1.9e+01	1	4.7e-02
Reactor Feedwater	6.9e+02	1	1.7e+00
Miscellaneous Wastes (Radioactive)	9.0e+00	1	2.2e-02
Total			**4.4e+00**

Table A-23 (continued)

Building/Associated Equipment/System/Structure	Contaminated Area (m^2)	Contamination Level	Deposited Activity (Ci)
Radwaste and Control Building			
Condensate Filter Demineralizer	3.6e+02	2	9.0e+00
Condenser Off Gas Treatment	3.2e+02	1	8.0e-01
Equipment Drain (Radioactive)	4.3e+01	1	1.1e-01
Equipment Drain (Radioactive)	1.8e+02	2	4.5e+00
Floor Drain (Radioactive)	1.2e+01	1	3.0e-02
Floor Drain (Radioactive)	1.9e+02	2	4.8e+00
Floor Pool Cooling & Cleanup	5.4e+01	2	1.4e+00
Miscellaneous Wastes (Radioactive)	2.4e+01	1	6.0e-02
Miscellaneous Wastes (Radioactive)	1.9e+02	2	4.8e+00
Process Waste (Radioactive)	1.8e+02	1	4.5e-01
Process Waste (Radioactive)	2.7e+02	2	6.7e+00
Reactor Water Cleanup	1.3e+02	2	3.2e+00
Total			**3.6e+01**

Source: Oak et al. 1980

Note: Estimated total deposited radioactivity on contaminated external surfaces = 1.14×10^2 Ci

Model Estimates Versus Empirical Data

External surface contamination corresponding to Level 1 (2.5×10^{-3} Ci/m^2 or 5.2×10^7 dpm/100 cm^2) and Level 2 (2.5×10^{-2} Ci/m^2 or 5.5×10^8 dpm/100 cm^2) is not uncommon and has been observed in most reactor facilities. Table A-24 presents study data that focused on the most highly contaminated surfaces at six nuclear power plants (Abel et al. 1986). Contamination levels corresponding to modeled values (i.e., Level 1 and Level 2), however, were restricted to small areas that had experienced spills, leaks, or intense maintenance, such as the reactor sump area, RCS coolant pumps and radwaste system components. The study data also showed that when surfaces were coated with sealant or epoxy paint, nearly all contamination resided on or within the surficial coating and was readily removable.

In summary, the modeled external surface contamination levels cited by Oak et al. (1980) for the Reference BWR appear excessive in terms of their projected surface areas and total plant inventory. The primary model parameter regarding the release of one liter of primary coolant per day that is allowed to buildup over a forty-year period of plant operation is not only without technical basis but ignores the ongoing decontamination efforts that exist at all nuclear facilities. For these reasons, the modeled data cited by Oak et al. (1980) are not considered suitable for characterizing the contaminated material inventories of BWR power plants.

Table A-24. External Surface Activity Concentrations at Six Nuclear Generating Stations

Radionuclide	Areal Activity Concentration		
	Range (pCi/cm^2)	Average ($dpm/100\ cm^2$)	N*
Co-60	590 - 460,000	2.4e+07	5
Ni-59	30 - 2,400	1.9e+05	3
Ni-63	3,100 - 6,400	1.0e+06	2
Sr-90	1.6 - 480	3.7e+04	4
Tc-99	0.27 - 2.4	3.5e+02	3
Cs-137	550 - 2.0 E6	8.1e+07	6
Eu-152	9 - 3,100	2.2e+05	3
Eu-154	90 - 1,500	1.5e+05	3
Eu-155	10 - 500	1.3e+04	2
Pu-238	0.025 - 48	3.1e+03	4
Pu-239, 240	0.089 - 21	1.7e+03	4
Am-241	0.10 - 30	1.9e+03	4
Cm-244	0.013 - 0.026	3.5e+00	3

*Number of reactor units included in calculation

A.3.3.2 Surface Contamination Levels Reported by Facilities Preparing for Decommissioning

PWR

By coincidence (as was previously noted), the Trojan Nuclear Plant (TNP), which was used as the Reference PWR facility by Smith et al. (1978), has been permanently shutdown and has submitted a decommissioning plan. External surface contamination inventories at this facility are summarized in TNP's decommissioning plan and have been reproduced in Table A-25. Estimates were based on historical survey data and recent structural surveys performed in support of the radiological site characterization required by the decommissioning plan.

Combined radionuclide inventories in the containment building, auxiliary building, fuel building and the main steam support structure are estimated to be 30 mCi. Note that this value is about three orders of magnitude lower than the estimate for the Reference BWR modeled by Oak et al. (1980), presented in Table A-23.

Table A-25. Radionuclide Inventories on External Surfaces at Trojan Nuclear Plant

Structure	Total Activity (mCi)
Containment Building	24
Auxiliary Building	2
Fuel Building	1
Main Steam Support Structure	1
Turbine Building	2
Total	30

More detailed data relating to contamination of external surfaces at TNP were recently cited in a draft report issued by the NRC (1994). The survey data primarily measured removable floor contamination levels obtained by smears. However, such measurements may reasonably be assumed to also represent metal surfaces of reactor systems and structural components.

A summary of removable external surface contamination levels at TNP are given in Table A-26.

Table A-26. Contamination of Floor Surfaces at Trojan Nuclear Plant Prior to Decommissioning

Building	Total Area (m^2)	Contaminated		Removable Surface Contamination ($dpm/100\ cm^2$)
		Fraction (%)	Area (m^2)	
Containment	1,900	100	1,900	1,100 - 55,000
Auxiliary (6 levels)	4,000	1 - 5	40 - 200	< 1,100 - 7,900
Fuel Building (5 levels)	5,000	1 - 5	50 - 250	< 1,100 - 5,000
Turbine Building	5,700*	<< 1	~ 0	< 1,000
Control Building	700*	<< 1	~ 0	< 1,000

Source: NRC 1994
* per level

The auxiliary and fuel buildings also exhibited some areas of floor contamination, but not to the extent of that observed in the reactor containment building. Based on survey reports, about 1% to 5% of the floor area (representing about 40 m^2 to 200 m^2) in the auxiliary building has radioactive contamination levels in the range of 1,100 to 7,900 $dpm/100\ cm^2$. The fuel handling building also has a small area of contaminated floor, ranging from 50 m^2 to 250 m^2, with contamination levels ranging of about 1,100 to 5,000 dpm per 100 cm^2.

Other buildings, including the turbine building and the control building, did not have measurable, removable contamination on any surfaces.

It is important to note, however, that the quantitative estimates in Table A-26 reflect contamination that is removable (i.e., by wiping a 100 cm^2 area with a dry filter paper). Reasonable estimates of total surficial contamination levels (i.e., fixed and removable) may be obtained by multiplying values in Column 5 of Table A-26 by a factor whose value may range from 5 to 10.

BWR

Values similar to those reported in the TNP's decommissioning plan have also been reported in the decommissioning plan submitted for Humboldt Bay Unit 3 (Pacific Gas and Electric 1994). Excerpts of survey measurements (as they appear in the decommissioning plan) are shown in Tables A-27 and A-28. Horizontal surfaces (i.e., floors) exhibited contamination levels that, on average, were about one order of magnitude higher than vertical surfaces (i.e., walls) with values ranging from below detection limits up to several million dpm per 100 cm^2 for certain floor areas (e.g., under the reactor vessel). When relatively small areas of high contamination are excluded, average external surface contamination was generally between 5,000 and 100,000 dpm/100 cm^2.

From the above-cited data, it is concluded that, within the common variability of contamination levels in nuclear plants, the survey data reported in decommissioning plans for the Trojan and Humboldt Bay facilities provide a reasonable basis for estimating surface contamination levels at other PWR and BWR power plants, respectively.

A.4 BASELINE METAL INVENTORIES

A.4.1 Reference PWR

The total amounts of metals contained in significant quantities in a typical 1,000 MWe PWR power plant have been quantified in a 1974 study of material resource use and recovery in nuclear power plants (Bryan and Dudley 1974). Material estimates were made using various methods that included: (1) amounts of raw materials purchased for construction (e.g., reinforcing steel and structural steel required for construction), (2) weights of materials contained in equipment and machinery based on manufacturers' specifications and technical journals (e.g., determination of carbon steel, stainless steel, copper and other metals in electric motors); and (3) the U.S. Atomic Energy Commission facility accounting system, which identified individual items.

Summary estimates of composite materials used to construct a 1971-vintage 1,000 MWe PWR power plant are given in Table A-29.

Carbon steel is the predominant metal used in the construction of a nuclear power plant. It is used in piping and system components when the need for corrosion resistant stainless steel is not of significant importance. A large percentage is also used in structural components that include rebar, I-beams, plates, grates and staircases. A breakdown of material quantities used in reactor plant structures and plant systems is provided in Table A-30. Structural components comprise 16,519 t out of a total of 32,731 t of carbon steel, with the remainder used in plant equipment. Of the more than 16,000 t of carbon steel employed in plant equipment/systems, 10,958 t are contained in turbine plant equipment. Barring significant leakage in steam generators, equipment in this grouping as well as electric plant equipment, equipment identified as "miscellaneous," and "structures" are not likely to be exposed to radioactive contamination and are therefore not likely to contribute significant quantities of residually contaminated scrap metal.

The primary sources of contaminated scrap metal in a PWR are underlined in Table A-30 and involve all items associated with reactor plant equipment with additional quantities contributed by "Fuel Storage," certain structural components, HVAC systems and other items that are identified in detail in Section A.5.

Table A-30 also shows that the use of corrosion resistant stainless steel is almost totally confined to reactor plant and turbine plant systems. Of the total 2,080 t of stainless steel, essentially all of the 1,154.6 t associated with reactor plant systems and the 21.1 t that line the fuel pool can be assumed to be contaminated.

A.4.2 Reference BWR

Inventories for a 1,000-MWe BWR reference plant have been estimated by adjusting Bryan and Dudley's 1974 Reference PWR plant data taking into account the characteristics of a BWR (Oak et al. 1980).

Table A-27. Radiation Survey Data for Humboldt Bay Refueling Building[a]

Location		Dose Rate[b] (mR/h)		Contamination Levels ($\mu Ci/100cm^2$)			
				Contact[c]		Smearable	
		Gamma	Beta	Alpha	Beta-Gamma	Alpha	Beta-Gamma
+12 ft elevation	floor	10	<1	f	3.6e-02	3.9e-06	1.1e-03
	wall			f	9.8e-03	2.2e-06	3.3e-04
Access Shaft -2 ft elevation	floor	7[g]	h	f	1.6e-02	7.1e-06	1.5e-03
	wall			f	2.1e-03	f	2.7e-05
-14 ft elevation	floor	2[g]	0	f	4.2e-03	4.7e-06	2.3e-03
	wall			f	2.4e-03	2.3e-06	7.6e-04
-24 ft elevation	floor	1[g]	h	f	3.1e-03	1.4e-05	2.4e-03
	wall			f	1.0e-03	f	f
-34 ft elevation	floor	1[g]	h	f	2.1e-03	1.2e-05	3.0e-03
	wall			f	f	f	f
-44 ft elevation	floor	7[g]	1.5	f	8.3e-02	4.5e-06	1.3e-03
	wall			f	1.0e-02	f	2.7e-05
-54 ft elevation	floor	18	1.1	f	1.2e-01	4.5e-06	1.2e-03
	wall			f	2.1e-02	f	f
-66 ft elevation	floor	12	0	f	1.4e-01	2.3e-06	6.1e-04
	wall			f	6.4e-02	f	f
Cleanup: HX Room -2 ft elevation	floor	65	0	f	1.0e-01	2.1e-05	9.4e-03
	wall			f	4.2e-02	f	1.9e-05
Cleanup: Demin Room -2 ft elevation	floor	6	1.5	f	2.1e-01	1.0e-04	4.2e-02
	wall			f	2.1e-03	2.0e-06	3.5e-04
Shutdown: HX Room -14 ft elevation	floor	55	1.1	f	f	3.7e-06	2.8e-03
	wall			f	2.1e-02	2.8e-07	2.0e-05
West Wing -66 ft elevation	floor	110	7.5	f	f	1.2e-05	2.7e-03
	wall			f	9.6e-02	5.6e-07	f
Under Reactor -66 ft elevation	floor	23	21	1.7e-03	2.0e+00	9.0e-04	3.3e-01
	wall			f	3.2e-02	6.5e-05	4.4e-03
New Fuel Vault +0 ft elevation	floor	5	47	3.4e-04	2.3e+00	1.9e-05	5.4e-03
	wall			f	f	1.1e-06	6.3e-04
TBDT Area -14 ft elevation	floor	23	35	f	1.6e-01	4.2e-06	9.6e-04
	wall			f	3.4e+00	1.1e-06	9.1e-03

[a] Average values of PG&E survey conducted May 1984 unless otherwise specified.

[b] Ion chamber

[c] Minimum sensitivity: alpha: 1×10^{-4} $\mu Ci/100cm^2$

beta: Cutie Pie 5×10^{-3} $\mu Ci/100cm^2$

HP-210 2×10^{-6} $\mu Ci/100cm^2$

[d] Based on Cs-137

[e] Based on Sr-90 (10%), Co-60 (45%) and Cs-137 (45%)

[f] Not detected

[g] Previous survey

[h] Data not recorded

Table A-28. Radiation Survey Data for Humboldt Bay Power Building[a]

Location		Dose Rate[b] (mR/h)		Contamination Levels (µCi/100cm²)			
				Contact[c]		Smearable	
		Gamma	Beta	Alpha	Beta-Gamma	Alpha	Beta-Gamma
Condensor/ Demineralizer Cubicle	floor	11	0	f	3.2e-02	8.5e-06	1.4e-03
	wall			f	3.2e-02	f	9.7e-05
Condensor/ Demineralizer Regeneration Room	floor	14	1.5	2.6e-04	3.5e-02	1.1e-05	2.7e-03
	wall			1.0e-03	7.1e-02	1.1e-05	1.5e-03
Condensor/ Demineralizer Operations Area	floor	14[g]	h	f	3.5e-03	1.4e-06	1.5e-04
	wall			f	8.8e-03	f	6.1e-05
Condensor Pump Room	floor	13[g]	h	f	f	2.0e-06	5.0e-04
	wall			f	f	f	2.8e-05
Air Ejector Room	floor	55	56	f	5.6e+00	1.7e-06	7.8e-02
	wall			f	f	h	1.5e-03
Condenser Area	floor	19	<1	f	6.0e-03	5.7e-07	5.7e-04
	wall			f	f	h	h
Pipe Tunnel	floor	15	1.5	f	4.7e-03	1.1e-06	2.9e-04
	wall			f	f	1.4e-07	2.1e-05
Feed Pump Room	floor	<1[g]	h	f	5.2e-04	f	8.4e-05
	wall			h	h	h	h
Seal Oil Room	floor	0.005[g]	h	f	f	f	2.1e-05
	wall			h	h	h	h
Turbine Enclosure +27 ft elevation	floor	<1[g]	h	f	3.1e-03	8.5e-07	1.2e-04
	wall			f	4.2e-03	2.8e-07	f
Turbine Washdown Area +27 ft elevation	floor	<1[g]	h	f	1.0e-03	1.7e-06	6.1e-05
Hot Lab	floor	<1[g]	h	f	1.2e-02	f	7.3e-05
Laundry/Demin Area +27 ft elevation	floor	<1[g]	h	f	2.6e-03	4.3e-07	7.7e-05
Laundry/Hot Lab +34 ft elevation	floor	h	h	f	1.0e-03	f	2.0e-04

[a] Average values of PG&E survey conducted May 1984 unless otherwise specified

[b] Ion chamber

[c] Minimum sensitivity: alpha: 1E-4 µCi/100cm²
beta: Cutie Pie 5E-3 µCi/100cm²
HP-210 2E-6 µCi/100cm²

[d] Based on Cs-137

[e] Based on Sr-90 (10%), Co-60 (45%) and Cs-137 (45%)

[f] Not detected

[g] Previous survey

[h] Data not recorded

Table A-29. Inventory of Materials in a 1971-Vintage 1,000 MWe PWR Facility

Metal	Total Mass (t)
Carbon Steel	**3.3e+04**
Rebar	1.3e+04
All Other	2.0e+04
Stainless Steel	2.1e+03
Galvanized Iron	1.3e+03
Copper	6.9e+02
Inconel	1.2e+02
Lead	46
Bronze	25
Aluminum	18
Brass	10
Nickel	1.0
Silver	< 1.0

Source: Bryan and Dudley 1974

With regard to the steel inventories, there are two significant differences between a PWR and BWR. A BWR has less heat-transfer piping and lacks a steam generator, but has more extra-vessel primary components, including a pressure suppression chamber. A second difference is the estimated quantity of rebar used for concrete reinforcement. Of the 32,700 tons of carbon steel in the Reference 1,000 MWe PWR, Bryan and Dudley estimated that about 13,300 tons is rebar; for the 1,000 MWe Reference BWR, the total mass of rebar was estimated at 18,300 tons (Oak et al. 1980).

Although the amount of steel required to construct a BWR is only slightly greater than for a PWR, a greater fraction of the steel (and other metals) is contaminated. This is because primary-to-secondary leakage causes radioactive contamination of the BWR steam flow, which in turn contaminates turbine plant equipment; in a PWR, such equipment is usually uncontaminated.

Table A-31 identifies material estimates for a 1,000-MWe BWR plant. Material estimates for metals other than carbon and stainless steel for the 1,000-MWe Reference BWR are assumed to be identical to those of the 1,000-MWe Reference PWR.

Table A-30. Breakdown of Materials Used in PWR Plant Structures and Reactor Systems (t)

System	Carbon Steel	Stainless Steel	Galvanized Iron	Copper	Inconel	Lead	Bronze	Aluminum	Brass	Nickel	Silver
Structures/Site	16519.3	28.6	814.2	33.1	0	33.1	0.2	1.2	2.9	0.1	0.1
Site Improvements	1692.9	0.0	17.9	1.5	0.0	0.7	0.0	0.1	0.0	0.0	0.0
Reactor Building	7264.2	5.7	301.2	9.3	0.0	0.0	0.0	0.1	0.3	0.0	0.0
Turbine Building	3641.2	0.0	196.4	1.6	0.0	0.0	0.1	0.8	1.4	0.0	0.0
Intake/Discharge	333.7	0.0	3.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reactor Auxiliaries*	1358.7	0.0	109.8	0.8	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Fuel Storage	364.6	21.1	43.4	0.3	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Miscellaneous Bldgs.	1864	1.8	141.9	19.4	0.0	32.4	0.1	0.1	0.9	0.1	0.1
Reactor Plant Equipment	**3444.9**	**1154.6**	**5.5**	**50.4**	**124.1**	**4.5**	**0.5**	**5.2**	**0**	**0**	**0**
Reactor Equipment	430.0	275.1	0.0	6.8	124.1	0.0	0.0	0.0	0.0	0.0	0.0
Main Heat Trans. System	1686.5	202.5	1.6	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Safeguards Cool. System	274.2	199.1	1.1	2.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Radwaste System	35.2	31.9	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Handling System	82.0	67.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Reactor Equipment	823.5	230.3	1.7	1.5	0.0	4.5	0.4	0.0	0.0	0.0	0.0
Instrumentation & Control	113.5	148.7	0.0	29.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0
Turbine Plant Equipment	**10958.3**	**883.2**	**4.7**	**51.4**	**0.0**	**0.0**	**21.5**	**1.2**	**6.9**	**0.0**	**0.0**
Turbine-Generator	4138.6	129.9	0.5	35.2	0.0	0.0	19.7	0.0	0.0	0.0	0.0
Heat Rejection Systems	2501.1	9.1	2.2	3.0	0.0	0.0	0.7	0.0	0.4	0.0	0.0
Condensing Systems	1359.8	392.3	0.6	1.3	0.0	0.0	0.3	0.0	1.5	0.0	0.0
Feed-Heating System	1367.7	221.2	0.5	1.2	0.0	0.0	0.3	0.0	3.9	0.0	0.0
Other Equipment	1541.3	89.4	0.9	0.7	0.0	0.0	0.5	0.0	1.1	0.0	0.0
Instrumentation & Control	49.8	41.3	0.0	10.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
Electric Plant Equipment	**965.5**	**0.0**	**431**	**556.5**	**0.0**	**6.8**	**2.5**	**4.1**	**0.0**	**0.6**	**0.4**
Switchgear	30.4	0.0	1.4	2.8	0.0	0.0	0.7	0.0	0.0	0.0	0.3
Station Service Equip.	654.1	0.0	8.5	19.0	0.0	6.8	0.7	0.0	0.0	0.0	0.1
Switchboards	87.0	0.0	0.0	13.5	0.0	0.0	0.1	4.1	0.0	0.0	0.0
Protective Equipment	5.9	0.0	0.0	39.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Structures & Enclosure	112.5	0.0	421.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Power & Control Wiring	75.6	0.0	0.0	482.2	0.0	0.0	0.5	0.0	0.0	0.6	0.0
Miscellaneous Equipment	**843.2**	**13.7**	**2**	**2.6**	**0**	**2**	**0.4**	**6.5**	**0.3**	**0**	**0**
Transportation & Lifting	529.3	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air & Water Service Sys.	232.5	6.0	0.0	1.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Communications Equip.	4.7	0.0	0.6	1.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Furnishings & Fixtures	76.7	7.7	1.4	0.0	0.0	2.0	0.4	6.1	0.0	0.0	0.0
Entire Plant	**32731.2**	**2080.1**	**1257.4**	**694**	**124.1**	**46.4**	**25.1**	**18.2**	**10.1**	**0.7**	**0.5**

Source: Bryan and Dudley 1974

* Underlined text identifies equipment/systems with significant amounts of radioactive contamination.

Table A-31. Inventories of Ferrous Metals Used to Construct a 1,000-MWe BWR Facility

Metal	Total Mass (t)
Carbon Steel	**3.4e+04**
Rebar	1.8e+04
All Other	1.6e+04
Stainless Steel	2.1e+03

Source: Oak et al. 1980

A.5 METAL INVENTORIES WITH THE POTENTIAL FOR CLEARANCE

From data presented in previous sections, two important conclusions can be stated: (1) only a fraction of metal inventories is likely to be significantly contaminated and (2) not all contaminated metal inventories are candidates for clearance. The potential for clearance is largely determined by the practicality and efficacy with which contaminated scrap can be decontaminated to an acceptable level.

The choice of available decontamination methods needed to make scrap metal candidates for clearance is largely dependent on the initial level of contamination, the type of surface, physical accessibility to the surface, the radionuclides involved and their chemical states, and the size and configuration of the metal object.

Several techniques are currently used in decontamination efforts at nuclear facilities. Their applicability, however, is not without restrictions and for nearly all approaches, there are numerous factors that affect their efficacy. Examples include the choice of cleaner/solvent/surfactant for hand wiping, the selection of chemical solvents for the dissolution and removal of radioactive corrosion films or base metal, or the innovative use of dry-ice (CO_2) pellets for abrasive blasting. These techniques and their general applicability and limitations are briefly summarized below.

Hand Wiping

Rags moistened with water or a solvent such as acetone can be an effective decontamination process. Wiping can be used extensively and effectively on smaller items with low-to-medium external contamination levels and easily accessible internal contamination. This method may not work well if the item is rusty or pitted. It requires access to all surfaces to be cleaned, is a relatively slow procedure, and its hands-on nature can lead to high personnel exposure. On the positive side, wiping can provide a high decontamination factor (DF), generates easily handled decontamination wastes (contaminated rags), requires no special equipment, and can be used selectively on portions of the component.

Steam Cleaning

This may be performed either remotely in a spray booth or directly by decontamination personnel using some type of hand-held wand arrangement. In the former case, only minimal internal decontamination is possible; however, reasonable external cleaning can be accomplished quickly while minimizing external exposure to direct radiation. Containment of the generated wastes and protection of personnel from radioactive contamination may be difficult, however.

Abrasive Blasting

This is a highly effective procedure even for surfaces that are rusty or pitted. As with hand-held steam cleaning, this method suffers from internal accessibility problems. It also generates large amounts of solid wastes and, being a dry process, produces significant quantities of airborne radioactive dust. Abrasive blasting may be used if its high effectiveness can be justified after taking into account the radiation exposures, generation of radioactive waste and limited accessibility to internal surfaces. Some of the aforementioned disadvantages are obviated when dry ice pellets are used.

Hydrolasing

The use of high pressure water jets for decontamination falls somewhere between steam cleaning and abrasive blasting in effectiveness. Less effective than abrasive blasting, it has the advantage of producing liquid wastes (that can be processed) rather than solid wastes. As an external cleaning technique, it has the advantage of reducing the generation airborne radioactive dusts, although this is offset by the potential of spreading contamination by splashing. The use of hydrolasing is generally limited to cases where access to internal surfaces is not required.

Ultrasonic Cleaning

Since this is an immersion process that is limited to smaller items, it is generally unsuitable for large-scale decontamination. Although ultrasonic cleaning can be especially effective in removing contamination from crevices, it is doubtful that clearance levels can be reached consistently with this technique to make it a viable option.

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